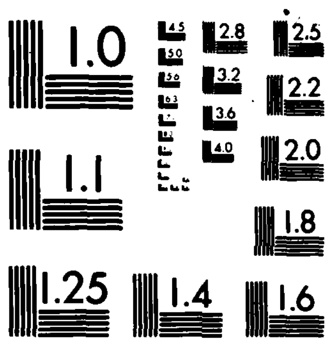
AD-A141 302 MICROWAVE RADIOMETRIC MEASUREMENT OF SEA SURFACE SALINITY(U) NAVAL OCEAN RESEARCH AND DEVELOPMENT ACTIVITY NSTL STATION MS G STANFORD APR 84 1/1

UNCLASSIFIED NORDA-TN-267 F/G 8/10 NL



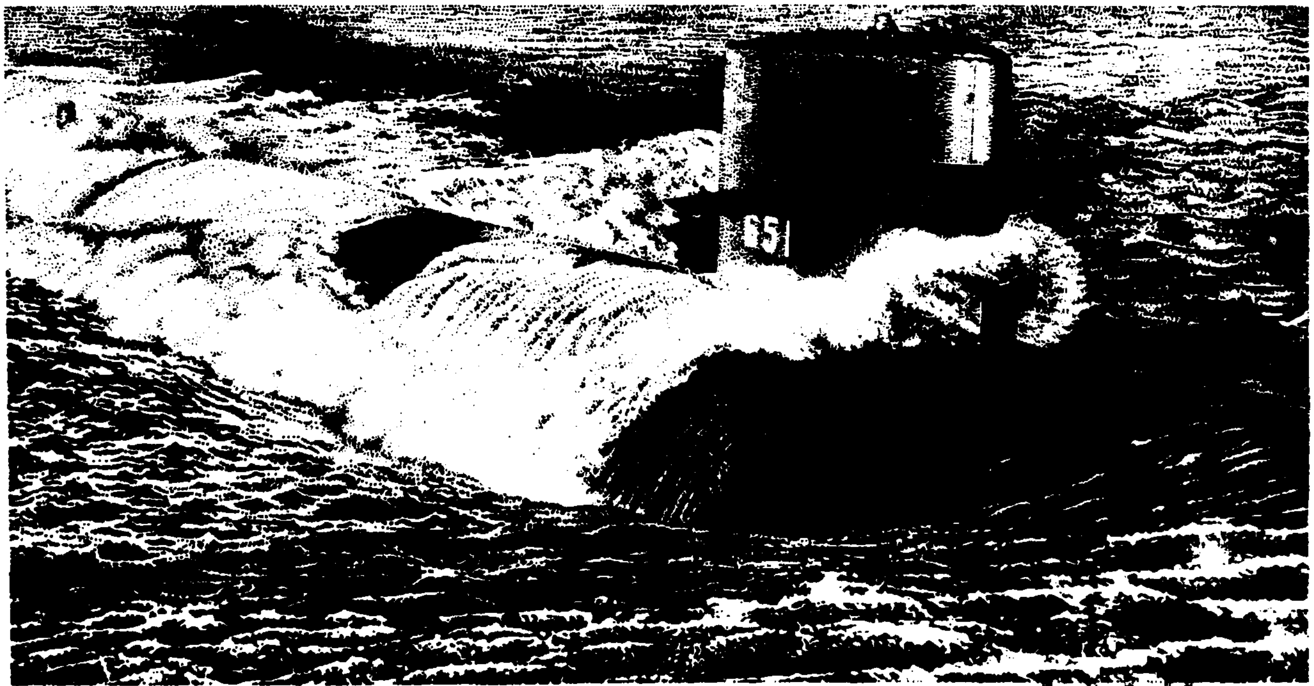
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

(8)

NORDA Technical Note 267

Naval Ocean Research and
Development Activity
NSTL, Mississippi 39529

Microwave Radiometric Measurement of Sea Surface Salinity



George Stanford
Requirements and Assessment Office

April 1984

ABSTRACT

The emphasis on salinity measurements in coastal areas has obscured the development of remote sensing of salinity in the open ocean. In part, this is due to the homogeneity of haline fields in the open ocean; however, one area where salinity measurement is important is the region along the edge of polar ice, the Marginal Ice Zone (MIZ). This report discusses microwave radiometric measurements of the MIZ and other areas with similar variations in surface salinity. The physics of the S-Band radiometer is discussed.

CONTENTS

MICROWAVE RADIOMETRIC MEASUREMENT OF SEA SURFACE SALINITY

1.0 INTRODUCTION

Due to their proximity to major population centers and the attendant economic and environmental impact upon these populations, estuarial and littoral areas have received intense scientific scrutiny. Both in situ and remote measurements have garnered numerous biological and physical data to carefully characterize the coastal regions. One parameter of considerable interest is salinity, which is linked to hydrographic circulation and potential problems of polution and urban water supplies. Although salinity can be measured from a surface vessel, economic considerations advocate maximum utilization of remote sensing, either from aircraft or satellite platforms.

This strong emphasis on salinity measurements in littoral areas has obscured the development of remote sensing of salinity in the open ocean. In part this is due to the relative homogeneity of haline fields far removed from coastal zones. However, there is at least one area in the open ocean where remote measurement of salinity is of considerable importance, the oceanographically dynamic region along the edge of polar ice, the Marginal Ice Zone.

NASA scientists recently designed a microwave radiometer to measure haline fields. If this S-Band design is utilized, instruments can be developed that can measure ocean salinity to within an absolute accuracy of 0.3-0.5 parts per thousand (ppt) over smooth water [1]. When this accuracy is available, it will be possible to infer coarse measurements of mass density and evaporation/precipitation. Although these remotely-sensed measurements are currently an order of magnitude short of the accuracy desired by oceanographers, aircraft platforms may provide some useful data, particularly in the study of evaporation/precipitation in the tropics and in coastal zones, where salinity variations spanning 0-35 ppt are common. In similar manner, these techniques can be employed in the Marginal Ice Zone (MIZ) where melting (producing fresh water) and freezing (producing brine) generate similar variations in surface salinity.

2.0 MEASUREMENT TECHNIQUE

Proper utilization of a microwave radiometer to measure sea-surface salinity entails an understanding of both the physics of emission and the complex dielectric constant.

2.1 PHYSICS OF EMISSION

Matter, when heated to an equilibrium temperature, will emit electromagnetic radiation, whose power spectrum is dependent upon Planck's radiation law. The units for this spectrum are watts per unit solid angle per unit area per wavelength. At microwave frequencies, Planck's law may be approximated by the classical Raleigh-Jeans expression. The total power received by the radiometer is calculated when this expression is multiplied by the effective collecting area of the receiver and integrated over the solid angle. This received power is normally expressed as the product of three parameters: 1. Boltzmann's Constant, 2. antenna temperature, and 3. receiver bandwidth. The antenna temperature is a function of the integral of the brightness temperature, which in turn is a function of both surface emissivity and

temperature. Note that the radiometer provides a measurement of antenna temperature; however, the brightness temperature is the desired quantity [2].

If the emissivity were unity, the microwave radiometer would provide a unique all-weather measurement of ocean temperature. Unfortunately, the emissivity of sea water is substantially less than unity, that is, e is approximately 1/3, and varies with salinity, temperature, and surface texture. Assuming the ocean surface is in thermal equalibrium, the emissivity is identically equal to the absorptive power. If the ocean fills a flat half-space, this absorptive power can be calculated by solving the boundary-value problem of an electromagnetic wave incident upon a plane interface between two dielectrics. In this case, the emissivity is properly defined as:

$$e = 1 - R$$

where R is the power reflection coefficient. Note there will be a value for e and R for both horizontal and vertical polarization. These reflection coefficients are solely functions of the angle of incidence measured from nadir and the complex relative dielectric constant of sea water. Thus, a quantitative definition of the surface emissivity has been established between the instrument parameters of polarization and viewing angle and the dielectric constant, which is a function of the physical properties, such as salinity and temperature. The emissivity is additionally an implied function of electromagnetic wavelength through the dielectric constant.

Emissivity changes dramatically with the angle of incidence for both vertical and horizontal polarization. The vertically polarized component increases with viewing angle, reaching a maximum value at the Brewster angle, and then abruptly dropping to zero. Conversely, the horizontally polarized component monotonically decreases to zero as the viewing angle increases to 90°.

Microwave radiometers not only receive radiation emitted from the ocean, but also from the galactic background and the intervening atmosphere. This additional radiation is frequency dependent. At frequencies below 1 GHz, the radiation from outer space adds a significant bias. Similar bias is added by radiation from water vapor, liquid water, and oxygen at frequencies exceeding 10 GHz. Consequently, optimum frequencies for surface salinity observations are constrained to a band from 2-6 GHz.

2.2 COMPLEX DIELECTRIC CONSTANT

Regardless of the viewing angle and radiation polarization, the crucial link between the remotely sensed data and the geophysical observables is the dielectric constant. The complex dielectric constant of sea water can be calculated at any frequency within the microwave band from the Debye expression; in this expression, the dielectric constant is a function of: 1. radiation frequency, 2. permittivity at very high frequencies, 3. relaxation time, 4. ionic conductivity, 5. permittivity of free space, and 6. static dielectric constant. Parameters 3, 4, and 6 are all functions of the temperature and salinity of sea water. Specific values of these quantities have been recently calculated by substituting given values of temperature and salinity into refined regression models [3]. The quoted accuracy of the resultant values of calculated dielectric constant is 0.2%, which results in brightness temperature uncertainties of about 0.09 K due to modeling of Debye parameters.

In 1977, Klein and Swift [3] examined the influence of salinity, temperature, and microwave frequency on changes in resultant brightness temperature. Calculations were performed for a nadir-viewing radiometer operating at 2.65 GHz (S band) and 1.43 GHz (L band). Their results demonstrate how the brightness temperature becomes more responsive to changes in salinity as the probing microwave frequency is lowered. This occurs because the ionic conductivity is a function of both temperature and salinity, and because conduction currents predominate over displacement currents as the microwave frequency decreases. Conversely, the 2.65-GHz data reveal a much greater sensitivity to changes in surface temperature than do the 1.43-GHz data when the salinity exceeds 26 ppt.

2.3 DEPTH OF PENETRATION

In electromagnetic radiation, the reciprocal of the voltage attenuation coefficient of the propagation vector is called the skin depth or depth of penetration into the medium. This skin depth indicates the distance into the medium where the power is reduced by e exp(-2), and is a coarse indicator of the thickness of the layer contributing to the thermal emission. At 1.43 GHz, penetration is approximately 10 cm in fresh water; it exponentially decreases an order of magnitude when the salinity concentration increases to values of 34-37 ppt. Depth of penetration also varies with frequency. For example, when the temperature and salinity are 20°C and 36 ppt, respectively, depth of penetration is 1 cm at 1 GHz; this depth decreases exponentially by an order of magnitude to 1 mm at 16 GHz.

2.4 MEASUREMENT ACCURACY

Of all the surface parameters that can be measured, those relating to the volume properties of the ocean place the most severe demands on the performance of the microwave radiometer. For example, a measurement of ocean temperature accurate to within 1 K and salinity to within 1 ppt requires brightness temperature to be measured to an accuracy of 0.3-0.5 K.

For microwave frequencies lower than X band, accuracy of the dielectric constant of sea water is known to within 0.2%. If the ocean's surface is neither contaminated by concentrated pollutants nor disturbed by wind, the 0.2% accuracy requirement of the dielectric constant will enable surface temperature and salinity to be measured to within 1 K and 1 ppt, respectively.

Currently, varability in the emissivity due to surface roughness is inadequately explained by the physical optics/geometric optics model of rough surface emission. For example, experiments demonstrate that the thermal emission from very rough ocean surfaces is 5 K higher than predicted by the geometric optics model. However, the composite model comprising both large-scale and small-scale roughness appears to reconcile this discrepancy. Nevertheless, until the validity of the assumptions used in the composite model are demonstrated, either empirical corrections must be used or the radiometer should be pointed at the angle of incidence where the vertically polarized signal is roughness invariant. For this latter choice, spatial resolution will suffer due to the elongated footprint at this incidence angle.

2.5 SPATIAL RESOLUTION

Spatial resolution is determined by two factors: 1. the beam width of the antenna, and 2. the altitude of the radiometer above the surface of the earth. That is,

$$d = L*H/D$$

where d is the diameter of the resolution cell (the footprint), L is the electromagnetic wavelength, H is the altitude, and D is the diameter of the antenna aperture.

For useful microwave sensing in the Marginal Ice Zone, a spatial resolution of 1 km or less is needed. If the antenna is placed into a high shuttle orbit, for example, 500 km, the necessary antenna size is,

$$D = 100 \text{ m.}$$

If a swath width of 150 km is desired in the MIZ, the spacecraft advances one resolution cell approximately every 100 ms. If mechanical cross-track scanning is possible with a single radiometer, the integration time available per footprint is only 0.3 ms. This very short interval is insufficient for precise microwave measurements in the 1.4-8 GHz band.

3.0 EXPERIMENTAL RESULTS

Remote measurement of surface salinity has not received much attention from researchers, who have concentrated their efforts on more popular topics such as surface temperature, wind speed, altimetry, and ice studies. However, several measurements have been made that are notable.

3.1 MISSISSIPPI SOUND, 1972-1974

During a 3-year period, Thomann [4] conducted three aircraft and two helicopter experiments using two different 1.4-GHz radiometers. Temperature and salinity conditions were different for each experiment. Ground truth measurements were used to calibrate the data in each experiment. Root-mean-square deviations varying between 2 ppt and 3 ppt occurred between remote and ground truth boat measurements. Part of this deviation is attributed to position errors of the boat and aircraft during calibration. The results from this set of experiments suggests that in operational use accuracies exceeding 2 ppt can be achieved.

3.2 LOWER CHESAPEAKE BAY, 1976

As previously mentioned, because the microwave emission of ocean waters depends upon temperature and salinity, it is possible to use microwave radiometers to sense both sea surface temperature and salinity. The emission is more dependent on salinity at the lower microwave frequencies and more dependent on temperature at the higher microwave frequencies. Thus, two microwave radiometers, operating at 1.43 GHz and 2.65 GHz, provide a remote measurement of both parameters. The use of a dual-frequency radiometer system features an important advantage over many other types of remote sensing systems because it can operate at night and above clouds. These virtues could be significant for measurements in the Marginal Ice Zone.

Blume and his colleagues [5] utilized a dual-frequency radiometer system to measure sea surface temperature and salinity in the lower Chesapeake Bay. Their L-band (1.43 GHz) and S-band (2.65 GHz) radiometer system represents a third generation of advanced radiometers using null balancing and feedback noise injection for stabilization. After correcting for the influence of cosmic, radiation, intervening atmosphere, sea-surface roughness, and antenna beamwidth, sea-surface temperature with an accuracy of 1°C and salinity with an accuracy of 1 ppt were measured. These measurements from aircraft over the bay region and coastal area of the Atlantic Ocean produced temperature and salinity contour maps with spatial resolution of 0.5 km.

3.3 SAN FRANCISCO BAY DELTA, 1978

In contrast to the microwave radiometer measurements of Thomann and Blume, Khorram [6] attempted to use visual and infrared data to remotely measure estuarial salinity. Landsat multispectral scanner (MSS) data and color and color infrared photographs acquired from a U-2 aircraft were combined with surface measurements for salinity mapping of the delta. The salinity measurements and U-2 photography were obtained simultaneously and coincident with Landsat overpass. Based upon the analysis of natural color and color infrared photographs and Landsat color composite imagery, it was concluded that it was virtually impossible to establish any quantitative judgment regarding the salinity values by visual interpretation of the imagery.

Thus, there do not appear to be any alternatives to the use of microwave radiometers for the remote sensing of sea-surface salinity.

4.0 MEASUREMENT OPPORTUNITIES IN THE MARGINAL ICE ZONE

So far, discussion has been focused on surface salinity measurements of the littoral United States. In these temporate waters, summer salinity variability typically ranges from 16-32 ppt. There is similar, albeit diminished, varability in the polar MIZ. Two oceanographic experiments, conducted during September-October 1979 and February-March 1981 aptly illustrate salinity and temperature variability in this northern region.

4.1 CENTRAL BERING SEA ICE EDGE, 1981

Oceanographic observations by Muench [7] during February-March 1981 revealed a two-layered hydrographic structure for temperature, salinity, and density. This structure was confined to a 100 km wide band adjacent to the ice edge. The colder, lower-salinity upper layer was continuous in its temperature-salinity properties with homogeneous water to the north beneath the ice. The warmer, more saline water was similarly continuous with water to the south near the shelf break. The layered structure appears to be a regular winter feature associated with the ice edge in this region. Input of low-salinity water from melting ice along the edge is adequate to maintain the layered structure and its associated baroclinic circulation, against the effects of tidal and wind mixing.

A significant aspect of the observed temperature and salinity structure was the constancy of its position upon the shelf when compared with relatively large fluctuations in ice edge location during several storms. During one such storm from the south, the ice edge retreated approximately 100 km to the north. Surprisingly, the southern boundary of the two-layered structure moved northward only about 5 km. This

boundary displayed a similar invariance in location during a subsequent storm when the ice edge moved southward under the influence of northerly winds to virtually the same location it had occupied at the outset of the measurements. It is evident that the water column did not respond to the storms with lateral motions of the same magnitude as those exhibited by the ice edge.

A CTD transect extending from near the shelf break to the ice edge disclosed two interesting temperature and salinity features:

- Water in the northern part of the transect had near-freezing temperatures (less than -1.5°C), was low in salinity (less than 31.9 ppt), and was vertically homogeneous from surface to bottom.

- Water in the southern portion of the transect was warmer (greater than 1°C) and more saline (greater than 32.7 ppt) than that to the north and showed an almost vertically homogeneous structure just south of the two-layered region.

4.2 MARGINAL ICE ZONE NORTH OF SVALBARD, 1979

During September-October 1979 the Norwegian Remote Sensing Experiment [8] was conducted in the MIZ north of Svalbard. Conductivity, temperature, and depth (CTD) measurements were performed along tracks perpendicular and parallel to the ice edge, with spacings of several kilometers. The structure of the ocean in this area comprises three distinct water masses: 1. The Arctic surface water extends downward to 60 m and can be partitioned into two layers. A sharp pycnocline at about 20 m separates the fresh (32.35 ppt) mixed layer, with temperatures close to the freezing point (-1.7°C), from an intermediate layer below. This layer is nearly isothermal (-1.65°C) down to 60 m, with a strong halocline from 32.5-34.2 ppt. 2. The warm Atlantic Ocean water core is at about 250 m with a temperature near 1.5°C and a salinity of 34.9 ppt. 3. The Arctic bottom water extends from about 600 m to the bottom.

In the mixed layer adjacent to the ice edge, a weak horizontal frontal zone exists where the fresh (32.5 ppt) and cold (-1.7°C) water, which appears in the vicinity of the ice edge, encounters more saline (33.4 ppt) and warmer (-0.5°C) water. The horizontal distance between the ice edge and the frontal zone varied from 10-60 km, primarily because of changes in the wind direction and meandering of the frontal zone.

5.0 REFERENCES

[1] Swift, C. T. (1980). Report of the Working Group On Passive Microwaves. Boundary-Layer Meteorology, v. 18, pp. 329-333.

[2] Swift, C. T. (1980). Passive Microwave Sensing of the Ocean--A Review. Boundary-Layer Meteorology, v. 18, pp. 25-54.

[3] Klein, L. A. and C. T. Swift (1977). An Improved Model for the Dielectric Constant of Sea Water at Microwave Frequencies. IEEE Journal of Oceanic Engineering, v. OE-2, n. 1.

[4] Thomann, G. C. (1976). Experimental Results of the Remote Sensing of Sea-Surface Salinity at 21-cm Wavelength. IEEE Transactions On Geoscience Electronics, v. GE-14, n. 3.

[5] Blume, H. C. et al. (1978). Measurements of Ocean Temperature and Salinity Via Microwave Radiometry. Boundary-Layer Meteorology, v. 13, pp. 295-308.

[6] Khorram, S. (1982). Remote Sensing of Salinity in the San Francisco Bay Delta. Remote Sensing of Environment, v. 12, pp. 15-22.

[7] Muench, R. D. (1983). Mesoscale Oceanographic Features Associated With the Central Bering Sea Ice Edge: February- March 1981. Journal of Geophysical Research, v. 88, n. C5, pp. 2715-2722.

[8] Johannessen, O. M., J. A. Johannessen, J. Morison et al. (1983). Oceanographic Conditions in the Marginal Ice Zone North of Svalbard in Early Fall 1979 With An Emphasis on Mesoscale Processes. Journal of Geophysical Research, v. 88, n. C5, pp. 2755-2769.

DISTRIBUTION LIST

Commanding Officer
Naval Ocean Research and Development Activity
NSTL, MS 39529
ATTN: Code 100
Code 110
Code 113
Code 115
Code 125L
Code 130
Code 200
Code 201
Code 220
Code 240
Code 270
Code 300

Office of Naval Research Detachment
ATTN: Code 420
NSTL, MS 39529

Department of the Navy
Chief of Naval Operations
ATTN: OP-952D
Washington, DC 20350

Commander
Naval Air Development Center
ATTN: Mr. R. Bollard, Code 2062
Warminster, PA 18974

Commander
Naval Air Systems Command
Headquarters
ATTN: Mr. E. Davis, NAVAIR 370
Washington, DC 20361

Commander
Naval Air Systems Command
ATTN: PMA-264
Washington, DC 20361

Commanding Officer
Naval Coastal Systems Center
Panama City, FL 32407

Commanding Officer
Naval Research Laboratory
ATTN: Code 8000
Washington, DC 20362

Commander
Naval Oceanography Command
NSTL, MS 39522

Commanding Officer
Fleet Numerical Oceanogrpahy Center
Monterey, CA 93940

Commanding Officer
Naval Oceanographic Office
ATTN: Mr. M. Shank, Code 9000
NSTL, MS 39522

Commanding Officer
Naval Oceanographic Office
ATTN: Dr. W. Jobst, Code 7300
NSTL, MS 39522

Commander
Naval Ocean Systems Center
ATTN: Mr. R. Vent Code 6352
San Diego, CA 92152

Commander
Naval Sea System Command
ATTN: Mr. C. Smith, NAVSEA 63R
Washington, DC 20362

Commander
Naval Sea System Command
Headquarters
ATTN: PMS-402
Washington, DC 20362

Commander
Naval Sea System Command
Headquarters
ATTN: PMS-406
Washington, DC 20362

Commander
Naval Sea System Command
Headquarters
ATTN: PMS-407
Washington, DC 20362

Commander
Naval Surface Weapons Center
White Oak
Silver Spring, MD 20910

Commanding Officer
Naval Undersea Warfare
Engineering Station
ATTN: Mr. W. Anderson
Keyport, WA 98345

Commanding Officer
Naval Underwater Systems Center
ATTN: Mr. O. Waterson
Newport, RI 02840

Project Manager
ASW Systems Project (PM-4)
Department of the Navy
Washington, DC 20360

Officer in Charge
Naval Underwater Systems Center
ATTN: Dr. W. Schumacher, Code 312
New London Laboratory
New London, CT 06320

Officer in Charge
Naval Underwater Systems Center
ATTN: Mr. C. Brown, Code 311
New London Laboratory
New London, TC 06320

Defense Technical Information Center
ATTN: DTIC-DDAC
Cameron Station
Alexandria, VA 22314

Woods Hole Oceanographic Institution
86-96 Water St.
ATTN: Dr. E. Hays
Woods Hole, MA 02543

Applied Research Laboratories
The University of Texas at Austin
P. O. Box 8029
ATTN: G. Barnard
Austin, TX 78712

Applied Physics Laboratory
University of Washington
1013 NE 40th St.
ATTN: Mr. C. Sienkiewicz
Seattle, WA 98105

Applied Research Laboratory
Pennsylvania State University
P. O. Box 30, University Park
State College, PA 16802

Chief
Defence Research Establishment Atlantic
P. O. Box 1012
ATTN: Mr. O. Bluy
Dartmouth, NOVA SCOTIA B2Y3Z7
CANADA

Chief
Defence Research Establishment Pacific
Fleet Mail Office
Canadian Forces Base
Victoria BC VOS 1BO
CANADA

Ocean Data Systems, Inc.
ATTN: Mr. G. Jacobs
Rockville, MD 20852

Planning Systems, Inc.
ATTN: Dr. R. C. Cavanaugh
7900 Westpark Drive
McLean, VA 22101

Science Applications, Inc.
ATTN: Mr. W. D. Kirby
1710 Goodridge Drive
P. O. Box 1303
McLean, VA 22101

Scripps Institution of Oceanography
University of California
San Diego, CA 92152

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NORDA Technical Note 267	2. GOVT ACCESSION NO. [illegible]	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Microwave Radiometric Measurement of Sea Surface Salinity		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) George Stanford		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Ocean Research and Development Activity Requirements and Assessment Office NSTL, Mississippi 39529		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS same		12. REPORT DATE April 1984
		13. NUMBER OF PAGES 10
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

microwave	sea surface salinity
marginal ice zone	radiometer

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The emphasis on salinity measurements in coastal areas has obscured the development of remote sensing of salinity in the open ocean. In part, this is due to the homogeneity of haline fields in the open ocean; however, one area where salinity measurement is important is the region along the edge of polar ice, the Marginal Ice Zone (MIZ). This report discusses microwave radiometric measurements of the MIZ and other areas with similar variations in surface salinity. The physics of the S-Band radiometer is discussed.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

S/N 0102-LF-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

END

FILMED